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AIR POLLUTION AND RESPIRATORY DISEASE

Harry Heimann

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air pollution and respiratory disease

BY

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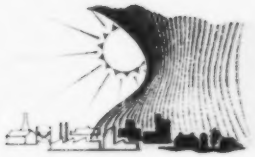

LET'S CLEAR THE AIR!

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FOREWORD

The United States is committed to the control of community air pollution. Passage of the Clean Air Act of 1963 marked the beginning of expanded emphasis on the national attack on air pollution. The cities and States of the country now have a new opportunity to initiate and develop programs for the prevention and abatement of air pollution on a scale more nearly adequate to the challenges they face. The development of the Federal Clean Air Act resulted from a growing awareness by the scientific community, the public, and the Congress that the adverse effects of community air pollution upon human health and welfare require a substantial increase in efforts to deal promptly and fully with the problem of air pollution.

This publication covers much of the accumulated knowledge of the relationship between air pollution and its effects on health developed from laboratory, clinical, and epidemiological research and from analysis of pertinent information from the field of occupational health. This report by a distinguished authority in the field of air pollution and public health should be of interest to State and local government officials, members of the health professions, and those other members of the public who are concerned with the problem of community air pollution and the need for its control.

Dr. Harry Heimann has made a noteworthy contribution to scientific knowledge of the health effects of air pollution both as a research worker and research administrator. His career with the Public Health Service has included numerous responsibilities which have contributed to his knowledge and experience in this area. In 1948, while serving as Chief of the Clinical Investigations Branch of the Division of Industrial Hygiene, Dr. Heimann directed the medical phase of the epidemiological investigation of the acute air pollution episode in Donora, Pa. In May 1956, Dr. Heimann was appointed

Chief of Operational Research of the Public Health Service's Community Air Pollution Medical Program, which had been established the previous year. In January 1959, he was designated Chief of the Medical Branch of that program, which, along with the Service's Air Pollution Engineering Program, formed the nucleus of the Division of Air Pollution, established in 1960. In August 1962, he was appointed Assistant Chief of the Division of Air Pollution. In October 1963, the Surgeon General appointed Dr. Heimann Chief of the Division of Occupational Health, a position he held until his retirement from the Public Health Service in November 1964. Dr. Heimann is now a member of the faculty of the Harvard University School of Public Health.

The Public Health Service is pleased to make available this monograph by Dr. Heimann for all who share a deep concern for the preservation of the most precious of our natural resources—the air we breathe.

VERNON G. MacKENZIE
Assistant Surgeon General
CHIEF, DIVISION OF AIR POLLUTION
PUBLIC HEALTH SERVICE

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air pollution and respiratory disease

Introduction

It is a truism that the air we breathe is essential to our health and well-being. However, when that air is laden with extraneous substances—when there is air pollution—then, although still essential to our good health, the air can also produce undesirable health effects.

In this discussion we shall consider only the recognizable manmade air pollutants. We shall omit naturally occurring airborne materials such as pollens, microorganisms (bacteria, viruses, spores, and molds), and those air contaminants arising from forest fires, dust storms, volcanic eruptions and the like, for these are relatively uncontrollable. We shall also omit from our discussion radioactive energies and materials, since they would take us into another scientific sphere of interest.

In limiting our discussion to the health effects of manmade air pollutants, we do not mean to deny the great importance of the chemically polluted atmosphere as a cause of reduction of visibility, direct damage to fabrics, metals, building stone and surface coatings, and agricultural damage, including destruction of vegetation and injury to farm animals. For our purpose, we shall consider only the effects on the health of man. Going one step further, we shall restrict ourselves to diseases of the respiratory system, for this is the organ complex most likely to be attacked by air pollutants.

Data are now available indicating that we are running out of safe, clean, usable water, partly because we are dumping so much of our refuse into our main water sources, our streams. So, too, we appear to be running out of clean air in many of our more populous and industrialized areas, and for similar reasons.

The main source of air pollutants is combustion, the burning, essentially, of fossil fuels (coal, oil, and natural gas) and many of their derivatives. Manmade (and only partially controlled) combustion, so very vital to our society, results in numerous products which are useful and desirable; but some are useless and highly undesirable. The undesirable ones are especially unwelcome when they are discharged in an uncontrolled manner into our air, a limited natural resource.

If we stopped burning, the bulk of manmade air pollution would be eliminated; but the price that civilization would pay would be prohibitively exorbitant. It is unreasonable even to contemplate that we could, with impunity, stop all combustion, not only the chief cause of manmade air pollution, but also the principal source of our energy needs. It is reasonable and logical, therefore, to consider that cleaning the air is both feasible and desirable. This can be done by abating air contaminants at their source.

How clean should the air be? This will vary with circumstances. Both the amount and kinds of contaminants are significant in this regard. In general, it must be remembered that whatever other uses man may devise for it, air is still essential for breathing! It must be kept clean enough to serve that primary purpose.

Although air pollutants were undoubtedly present earlier, they began to create a serious problem shortly after the discovery of coal in the 12th century in England. At that time, legal efforts to control the use of this fuel were not effective. And so, as the decades passed and Western Civilization in the 18th and 19th centuries went into the Industrial Revolution with its increasing need of coal as an energy source, the seeds had already been sown to aggravate air pollution to a level sufficient to arouse real complaints, and to be a real cause for alarm. Air pollution has been the cause of moderate public clamor at irregular intervals over the centuries due to its alleged and real harmful effects, but it is only in recent years that an aroused public has become especially vocal, insisting that the matter be corrected.

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The Acute Episodes

Not the least among the spurs to public clamor for positive action was the public awareness caused by several acute air pollution episodes that directly resulted in large amounts of sickness and many deaths in the Meuse Valley, Belgium, in 1930, in Donora, Pa., in 1948, and in London, England, in 1952.

In each of these three well-documented episodes of acute air pollution there was a prolonged period of unusual weather conditions which resulted in a failure of the usual natural air dilution and dissipation of air pollutants. As a result, the accumulation of pollutant mixtures soon reached much higher levels of concentration than was usual, concentrations that were high enough to be injurious to man.

In the first week of December 1930, during the occurrence of a thick fog that covered all of Belgium, the Meuse River Valley, along a highly industrialized 15-mile stretch, was afflicted not only with still, wet, cold air but also with an "inversion" of the air temperature. In such a weather "inversion" the air at ground level, instead of being warmer than the air above it as it usually is, is actually cooler and, therefore, does not rise in the normal manner to permit other (cleaner) air to move in. This lack of usual convection currents (together with the lack of wind) caused an accumulation of pollutants in the still and stagnant air of this industrialized community. The gases and extremely fine solid and liquid discharges from household chimneys and factory smokestacks soon reached noxious levels of concentration. This took its toll among the people residing in the valley. In the short period of a few days, thousands became ill and 60 people died of disease related primarily to the lungs and the heart. Early symptoms included dry or productive cough

and breathlessness. The immediate cause of the symptoms was believed to be the irritant material that people were forced to inhale with each breath. Death reached out to the elderly and to those who were already very ill from disease of the respiratory system or of the heart when the episode began.

A similar event took place in our own country in 1948. During the last week of October, a temperature inversion and an anticyclonic weather condition, characterized by little or no air movement, occurred over a wide area of the northeastern portion of the United States. The unusually prolonged atmospheric condition resulted in the accumulation of atmospheric contaminants to abnormal levels, particularly in highly industrialized areas. The city of Donora, Pa., was one such area. There the concentrations of noxious substances reached levels that were high enough to cause serious effects.

Donora, a town of some 14,000 population, is located in a deep valley on the inside of a sharp horseshoe bend of the meandering Monongahela River, about 30 miles south of Pittsburgh. On the morning of October 27, 1948, the atmosphere of Donora became very still: there was a marked weather inversion, and fog enveloped the city. The condition continued until October 31, when an air-cleaning afternoon rain occurred. In that interval of 4 days there was a great deal of respiratory illness among the residents. During that same period there were 17 deaths in the community which normally experienced an average of 2 deaths in an equivalent period at this time of year.

Cough was the single dominant symptom. After cough, the frequency of other symptoms was in the following descending order: soreness of throat, a feeling of chest constriction, headache, breathlessness, a burning sensation of the eyes, lacrimation (tearing), vomiting, nausea without vomiting, and excessive nasal discharge. Neither the prevalence nor the severity of illness was influenced by sex, race, occupational status, length of residence in the community, or degree of physical activity immediately preceding the time that the symptoms began. There was, however, a relationship between increasing age and both frequency and severity of illness.

The illnesses of the largest number of persons began on the third day of the episode. Of the 17 deaths, 15 occurred on the third day of the incident. The ages of the persons who died ranged from 52 to 81 years, with a mean of 65 years. Preexisting disease of the cardio-respiratory system appeared as the single significant common factor among the fatally ill.

Autopsies were performed on five bodies: three were of fatalities that occurred during the episode, and two of persons who died soon after. Of these, three showed acute irritative changes of the lungs, characterized by capillary swelling, haemorrhage, oedema, purulent bronchitis and purulent bronchiolitis. Chronic cardiovascular disease, the origin of which long antedated the episode, was a prominent finding in the autopsy examinations. This confirmed the conclusion, previously reached on clinical grounds, regarding the significance of preexisting heart disease in the illness that developed during the episode.

The third serious acute air pollution episode occurred in London in 1952. Here, between December 5 and 9, the weather conditions allowed an accumulation of air pollutants to take place and formed a "pea soup" fog. A few months later, after mortality statistics were reviewed, it was found that London had experienced 4,000 excess deaths in a 7-day period, the first day of which was the first day of the 5-day fog of December 1952. That is to say, in that period 4,000 more people died than was usual for a corresponding week in the immediately preceding years. A large number of persons became ill during the period. Here, too, as in the other two episodes, the illness and death increases were from illnesses of the cardio-respiratory system. Here, too, the unfortunate persons were affected by gases and particulate substances that were irritant to their respiratory systems.

Postscripts need to be noted in regard to the Donora and London episodes. There is strong suspicion that persons who were adversely affected at the time were more likely to have poor health subsequently. This would indicate that the acute air pollution episode can produce a lasting effect upon the health of those who live through it.

These episodes that we have briefly mentioned had much in common: all lasted only a few days; all were associated with unusual weather conditions; the fatalities were especially marked among people with preexisting cardio-respiratory diseases; the mechanism involved in the symptoms apparently began as a chemical irritation of the air-exposed sensitive membranous surfaces of the body.

What was the specific material that was the immediate cause of the illnesses produced? We must admit that in all three instances uncertainty existed

at the time and still exists now. It was generally believed by the investigators that a combination of ordinarily inert particulate material together with sulfur oxides was the culprit. Space will not permit us to expound on this hypothesis and its supporting data.

One rather interesting point developed from comparative studies of the reports of the acute episodes. In all three places, investigation of specific mortality rates together with weather conditions during the immediately preceding years, and the more remote past, proved that *similar incidents had occurred previously but had not been investigated or recorded.* Furthermore, in London there were later air pollution episodes as well, but of a milder nature. Such a report was made for New York City, in 1962, for an episode that had occurred in 1953, 9 years earlier. There, just as in the other communities that experienced the acute episodes, there was an unusual weather abnormality that allowed air pollutants to accumulate. This was associated with more illness and deaths from cardio-respiratory disease than one would "normally" have expected.

To know that an acute air pollution episode is developing or is in progress in a community requires only that the observer have a high index of suspicion and that he know how to read the "signs." With knowledge that is now available and good weather forecasting, this becomes a reasonable possibility. This happened as recently as December 1962, when London had another severe air pollution episode which was recognized immediately. The reports about that episode indicate that the toll taken of health and of life by this "smog" was appreciably less than it would have been had it occurred without immediate recognition. It was by virtue of this recognition that certain pragmatic steps were taken to prevent possibly more serious effects. Thus, the more sensitive persons who were known to have severe heart or lung disease were advised to remain indoors, away from the pollutants; many other people who were required to be outdoors covered their mouths and noses with simple gauze masks or with handkerchiefs to effectively filter out the larger airborne particles. (The fact that there were lesser amounts of airborne particulate materials than in the 1952 episode, partly because of control measures, undoubtedly contributed to this better experience.)

From these three classical and well-documented acute air pollution episodes, as well as other incidents, we learn that concentrations of pollutants in the community air can reach sufficiently high levels to cause immediate illness, aggravate preexisting illness, and, in unusual cases, lead to premature death. But these are not common happenings. In our form of society the usual situation is that pollutants are present in the community air at relatively

moderate and low levels of concentration. These are the situations that we have been studying and are now continuing to study to prove or disprove our early hypothesis that such lower levels of concentration, continued for extended periods of time—weeks, months, and years—also cause and aggravate illness, particularly illness of the respiratory tract. We believe that these lower concentrations of irritants, especially with their associated random peak levels, can injure the exposed membranes of our respiratory system, leading to disease of the underlying organs or aggravating disease of those organs.

What follows is a presentation of the evidence that we now have, in what ways our thoughts are directed to obtain more evidence, and what new avenues we are currently exploring. In doing this, we shall limit our presentation to the following respiratory diseases for which we have a significant amount of "proofs" of the association with air pollution: acute nonspecific upper respiratory disease, chronic bronchitis, chronic constrictive ventilatory disease, pulmonary emphysema, bronchial asthma, and lung cancer.

Acute Nonspecific Upper Respiratory Disease

In a 1950 study conducted in a small Maryland city, the household survey technique was used to collect information about the recent occurrence of a limited series of respiratory tract diseases, including the common cold. The data were correlated with the available air pollution intensities, those gaged by the index of dustfall measurements. It was found that, of two groups of people that were similar to each other in all of the important measures used, the group that lived in the part of town in which the dustfall measurements were higher had more common colds during the immediately preceding 30-day period than did the group that lived in the cleaner area.

Similar questioning about the occurrence of the following diseases failed to show a corresponding association with place of residence: acute tonsillitis, sore throat, acute bronchitis, acute sinusitis, laryngitis, and asthmatic attacks. The difference in the common cold frequency was found not to be due to differences in socioeconomic levels, age distribution, sex distribution, or variation in occupation between the two groups.

A similar observation was reported from the Soviet Union in 1957 for two adjacent communities, one having a relatively clean atmosphere and the other having high levels of air pollution. In that investigation, based upon objective medical examinations of the two equal socioeconomic groups and measurements of certain airborne gases and solids, it was found that, in addition to other illnesses, acute respiratory disease was appreciably more frequent in the community with the heavier air pollution.

These findings were, in a measure, further confirmed in reports of another American study still in progress. In this investigation of the sickness frequency among socioeconomically comparable groups of employees of several large industrial complexes with plants widely scattered about the country, it was indicated that air pollution, as measured by quantities of airborne solid sulfur compounds found in the communities where the workers lived, was associated with an increased occurrence (and probably an increased duration) of acute upper respiratory infections, limited to those that lasted 7 days or longer. The weather variations by themselves did not account for the difference.

Similarly, a recent report from Great Britain shows that rates for admissions for acute respiratory disease through the Emergency Bed Service to London hospitals over a 4-year period is closely correlated both with smoke concentrations in the air and with outdoor temperature. Reports from Japan also confirm that there is an association between air pollution and respiratory disease, especially upper respiratory disease.

These data point toward the inescapable conclusion that acute nonspecific upper respiratory disease is associated with moderate levels of air pollution, concentrations that are commonly found in our communities.

Experimental animal studies, however, have not been as consistent in their contributions to our understanding of this problem. In 1950 one investigator noted that a review of the subject of air pollutants in relation to acute infectious respiratory diseases, as well as her own negative laboratory experiments, led her to the opinion that one could not "draw any definite conclusions" from the then available data as to the relationship between chronic low-level air pollution and acute infections of the respiratory tract.

More recent studies, however, have repeatedly shown that animals exposed to the inhalation of low concentrations of an irritant gas (either ozone or oxides of nitrogen) and then challenged with aerosolized Klebsiella Pneumoniae organisms within a 24-hour period are more likely to develop fatal pneumonia than animals not previously exposed to the irritant in this manner. This finding was, in a sense, confirmed in an unreported finding from the U.S. Public Health Service Division of Air Pollution laboratories in which animals accidentally exposed to diluted automobile exhaust gas developed pneumonic infection; control animals housed adjacent to the accidentally gassed animals under identical conditions (except for the gassing), did not develop such pneumonic infection. Again, those animals that were pretreated with an irritant gas (diluted automobile exhaust) were apparently more prone to develop the lung infections. In this instance the source of the "causative" organism was not known.

Another important laboratory finding in this connection comes from studies of intact and excised animal tracheal epithelial tissue. This laboratory work has shown that when some of the irritant materials that are known to be present in community air supplies are applied to such preparations, not only does the mucus secretion increase, and at times thicken, but slowing, and even stoppage, of the movement of the hairlike cilia occurs in the airways. This loss of ciliary activity and the thickening of the mucus results in less effective removal of dust from the wall of these passages. These same irritant materials often lead to important cell changes and may at times be strong enough to cause the loss of protective surface cells, then permitting the more sensitive deeper cell layers to be exposed to whatever material may be carried in the air, including the irritant chemicals and even some infectious micro-organisms.

These suggestive laboratory findings may provide a working hypothesis for the explanation of the association that has been found between air pollution and acute nonspecific upper respiratory disease and even deeper lung infection. An alternative explanation may lie in a hypothesized air pollution-stimulated rise in virulence of the causative pathogenic organisms, either the many viruses known to cause the common cold or other mild acute upper respiratory disease, or the bacterial invaders that quickly follow upon the viral respiratory infection. This presumed, induced increase of relative virulence perhaps may occur in the micro-organisms while they are in the outdoor air or while they lie dormant on or within the surface of the respiratory linings.

Although fragmentary and circumstantial, and not always consistent, the field studies and the laboratory studies together provide strong evidence that air pollutants that are irritant to the respiratory tract are conducive to the development and prolongation of acute respiratory tract infections. Related field and laboratory studies are now in progress from which it is hoped to obtain satisfactory answers to the many questions that were raised by the completed investigations.

Chronic Bronchitis, Chronic Constrictive Ventilatory Disease, and Pulmonary Emphysema

This grouping was made to emphasize two points: The semantics involved in the medical diagnoses of these clinical complexes is imprecise and, when the conditions are considered physiologically and anatomically, they very often appear to fade into one another. One may actually find that two, or even all three, of the conditions coexist in the same patient. However, for the purpose of discussing these conditions in relation to air pollution, we propose to consider each of these conditions separately, to the degree that it will be possible for us to do so.

Chronic Bronchitis. This is a term frequently used as a clinical diagnosis in Great Britain, even though the criteria for this diagnostic term are not standardized at present. In Britain it is related causally to cigarette smoking as well as air pollution. It is a highly respected disease, since it is given as the cause of a great deal of illness and accounts for a significant portion of the British death rate. Nearly 10 percent of all deaths and over 10 percent of all industrial illness-absences in Britain are due to bronchitis. In the United States we are beginning to find that the condition has a higher prevalence than previously thought, now that we are actively looking for it, necessarily using arbitrary sets of diagnostic criteria for this purpose. Variations in prevalence of chronic bronchitis, not unlike those recorded by the British, have recently been observed and recorded in the United States. This variation is dependent upon the following factors: age, sex, social status, smoking habits, possibly community air pollution, and—certainly not the

least important—the definition of the disease itself. Its prevalence in this country, even then, does not seem to reach that of the British experience. One such search, using the criteria similar to those of the British (chronic productive cough most days for 3 months of each of 2 successive years) found chronic bronchitis in 21 percent of a group of 40–59 year old men. A recent report in the United States emphasizes the concept that here too chronic bronchitis can be a fatal disease by virtue of the associated cor pulmonale, even without any significant amount of pulmonary emphysema.

A recent American definition of this disease is as follows: "Chronic bronchitis is a clinical disorder characterized by excessive mucus secretion in the bronchial tree. It is manifested by chronic or recurrent productive cough. Arbitrarily, these manifestations should be present on most days for a minimum of three months in the year and for not less than two successive years." Obviously, other conditions such as pulmonary tuberculosis, bronchiectasis, and lung cancer, will need to have been ruled out as the cause of the symptoms.

Since chronic bronchitis is not generally a well-recognized clinical entity here, I shall defer to a British authority for its course description. At first there is simple bronchitis with "hypersecretion of bronchial mucus, manifest as chronic cough productive of mucoid sputum." This then progresses through "recurrent episodes of bronchial infection during which the sputum becomes purulent." Purulent sputum may then be continuous, and at this stage we have "chronic bronchitis with recurrent or persistent infection." Finally, some of these cases develop impaired pulmonary ventilation with partial airway obstruction. Breathlessness on exertion is then a frequent finding.

Both cigarette smoking and air pollution, as noted above, are given as separate causes of chronic bronchitis in Great Britain. Omitting tobacco from our purview for many reasons, we find that the evidence for the air pollution factor is indeed good. Many different air pollution indexes have shown positive associations with mortality from this disease. These studies were all done in Great Britain where the disease is of such high prevalence. Thus, in Britain the different population sizes of towns, used as a gage of air pollution, were shown to be directly associated with differences in chronic bronchitis mortality rates.

A second study showed an even better association between bronchitis mortality rates in 83 large towns and the amounts of fuel burned for domestic and industrial purposes. That conclusion held firm even after correction was made of the data for social status, a factor long known to be associated with bronchitis death occurrence.

Another investigation, based upon measures of sulfur dioxide air pollution in towns in England and Wales and mortality rates for bronchitis in persons over 45 years of age, showed that the higher mean annual sulfur dioxide measurements were associated with higher mortality rates among the men, and somewhat less so among the women. Again, varying social status did not account for the finding.

A fourth investigation along similar lines found that, even when the possible effect of population density itself was excluded, both settled dust intensities and airborne dust (measured by collection on air filters) were directly associated with mortality from this disease.

Finally, a study was reported in which decreased visibility, a measure of particulate air pollution that is finding scientific support, was the air pollution index used. This was compared to the bronchitis mortality rates for older persons in the whole of the United Kingdom, arbitrarily divided into 37 areas. Here again, there was a direct association between the index used and the mortality rate. In this study, again, when the bronchitis mortality rate was gaged against population density and domestic overcrowding, the association was not statistically significant.

In addition to the mortality studies, examination has been made of the aggravation of chronic bronchitis by air pollution. Among British postmen it was found that pollution, measured by the index of decreased visibility of the outdoor air, was positively associated with sickness absence rates and disability retirements for chronic bronchitis. Further, those postmen who worked outdoors, but who in other ways appeared to be similar to other postal service workers who worked indoors, suffered more from lost time from work due to bronchitis attacks. This fact was reasonably ascribed to the greater exposure to the outdoor air pollutants and not to the weather by itself.

Temporary air pollution increases have been found by different observers to cause aggravation of symptoms among known bronchitics. This has been reported repeatedly from a study in London in which the air pollution index was smoke and sulfur dioxide. Fog itself did not have the effect. Similar observations were made in Sheffield, England. In

the latter study it was also found that on those days on which pollution reached peak concentrations, the occurrence of new cases of disability from bronchitis was higher than on other days. Similar observations were also made for Salford.

In summary, we have the following: Data on chronic bronchitis in relation to air pollution have been developed in Great Britain, where the disease is of major significance. In America, we are only now beginning to find that the condition, or one closely allied to it, is not as unusual as had been previously believed; but studies in this direction in the United States have been very few. Therefore, basing our knowledge of the condition upon the British experience and their reports, we find that: (1) Chronic bronchitis mortality rates are associated with the following community air pollution indexes: population density, amount of fuel use, sulfur dioxide air levels, settled dust measures, airborne dust measures, and decreased visibility; (2) Aggravation of the condition, in the form of acute irritations, have been observed among British postmen employed in the more highly polluted areas, gaged by decrease of visibility; (3) Other things being equal, postmen who work outdoors lose more time from such illness than those who work indoors; (4) On days of higher pollution, a panel of chronic bronchitics kept under regular observation show a worsening of their illness. The circumstantial evidence, therefore, ties air pollution in a causal relationship to chronic bronchitis.

We do not now know with any degree of certainty the physiological mechanism that accounts for these facts. On a priori grounds it is believed that the epithelium-irritating qualities of the outdoor air pollutants is at least a factor in the mechanism.

Chronic Constrictive Ventilatory Disease. We apply the term chronic constrictive ventilatory disease to the long-continued, nonspecific, respiratory conditions in which the ventilatory defect of increased airway resistance appears to generally dominate the clinical picture, even though other symptoms or signs may also be present. It may, however, be without obvious symptoms and be found only by suitable objective test. Various other terms that have been used to denote the condition include "chronic nonspecific respiratory disease," "obstructive pulmonary disease," and "obstructive ventilatory disease." This group of cases consists of a miscellany of conditions, including chronic bronchitis, pulmonary emphysema, bronchiectasis, and even a few cases of cor pulmonale.

Although complicated to a degree by the influence of smoking, a definite association has been observed between cases of chronic constrictive ventilatory disease and certain measures of air pollution. For example, in a study of road tunnel workers, chronic nonspecific respiratory disease and ventilatory deficiencies occurred with greater frequency in those who were employed for 10 years or longer than in those who were employed for shorter periods. Age alone was not the cause. Although the factor of smoking as a cause was not entirely ruled out in that study, it appeared that duration of employment was associated with the medical condition.

In another study of two adjoining communities in western Pennsylvania, each with a population of slightly under 1,000, in which air pollution appeared to be the principal environment variable, we found that airway resistance was increased for the people who lived in the town with the greater pollution.

Laboratory experimental work with both animals and humans has shown that such irritant air pollutants as sulfur dioxide, sulfur trioxide, and others, at air concentrations similar to those frequently found in community air, can cause such airway constriction with resultant ventilatory obstruction.

The physiological significance of these seemingly minor deviations in lung ventilation is not now easy to assess. This is especially true when the persons involved have no subjective symptoms. However, it appears reasonable to suspect that the extra burden of the added resistance to air movement in the lung airway—even though of a minor importance when it is isolated and occurs in a healthy individual—may be functionally significant or may even become unbearable for those persons whose cardiorespiratory systems are already functioning "marginally" because of disease. The lung or heart injury that may follow the long-continued, or periodic, appearance of this functional abnormality in the presumably healthy person must be left to conjecture at this time.

Emphysema. The last medical condition to be considered in this group is pulmonary emphysema, an abnormal inflating of the lungs which makes normal breathing difficult. There is growing evidence that sickness and death from emphysema are increasing in the United States. Some British physicians believe that many of the emphysema cases in our country would be called chronic bronchitis by them. The fact that this disease is increasing, especially in urban areas, points toward air pollution as a possible causal factor.

From the Social Security Administration of the U.S. Department of Health, Education, and Welfare the following data in regard to emphysema sickness were recently developed. During 1961, 241,060 persons received monthly benefits for serious illness from the Old Age and Survivors Insurance plan of the Social Security System. Of this group there were 6.3 percent (or 15,271) for whom the primary medical diagnosis was pulmonary emphysema, including some cases of closely allied medical conditions. The corresponding figures for 1958, 1959, and 1960, were 5.9, 6.7, and 6.9 percent, respectively. The relatively high prevalence of the disease, as well as what appears to be a progressive annual increase from 1958 through 1960, are of interest.

The patient who has pulmonary emphysema becomes even more ill when he is exposed to irritant air pollution. One study of this problem showed that when such patients are placed in a room in which the outdoor air of a smoggy Los Angeles day is cleaned by electrostatic precipitation and charcoal filtration, they show marked improvement after only 24 hours.

Bronchial Asthma

Interest in the relation of irritant air pollution to bronchial asthma extends back at least to the acute air pollution episodes that were described earlier. In those three classical episodes, persons with chronic lung disease, including bronchial asthma, were likely to have become especially ill during the episodes.

The report of the Donora episode probably provides the most complete data in this connection. In Donora there were 340 persons (2.4 percent) of the approximately 14,000 residents who had been told by their physicians that they had bronchial asthma. Of these 340, 83 percent were made ill by the smog, in comparison with 43 percent of the town population as a whole. Furthermore, whereas only 10 percent of the entire population were "severely" affected, according to the arbitrary criteria established for the data analysis, among the known asthmatics, 57 percent had the "severe" form of the smog affection. These facts can be presented in another way: Compared with other people, asthmatics were twice as likely to become ill during the episode; further, their illnesses were much more likely to be severe. There can be no doubt that known bronchial asthmatics were strongly affected by the Donora smog.

It is important, in terms of case prevalence, to discuss the recent discovery of a disease believed to be due to airborne irritants and which at first was suspected of being atypical asthma. There are strong indications here that irritant air pollutants can induce attacks of this asthmalike condition in epidemic proportions. The first of such instances brought to our attention was found in the personnel and dependents of the American occupation forces in Japan shortly after the second World War. As early as 1946 there appeared among the American troops stationed in the highly industrialized Yokohama area of Japan a condition which was considered to be an epidemic of asthmatic bronchitis. Soon the condition appeared among the dependent family members of the military. If the disease was also present in the Japanese population, this fact was not brought to the attention of our military medical personnel. Evacuation of the cases from the area appeared to be the only way to treat these cases since they did not respond to the usual medication for asthma. Such evacuation generally resulted in disappearance of the symptoms. In time it was recognized that the disease was also occurring in our military people in the Tokyo area. In fact, the whole of the rapidly industrializing Kanto Plain, a 90- by 130-kilometer geographic bowl surrounded by mountains on three sides and the sea on the fourth, was the locus of the disease.

The typical patient was a healthy American adult, without a personal or family history of asthma or other allergy, who, in his first year (or less likely, in his second year) of residence in the heavily industrialized Kanto Plain, developed a nocturnal chronic dry cough that was complicated by wheezy and difficult breathing. At this stage the case resembled typical bronchial asthma, but the condition responded poorly to the usual therapy for bronchial asthma.

Early removal from the area resulted in rapid recovery. Even later removal generally had favorable effects. Return to the area resulted in symptoms and signs that were possibly more severe than at first.

Not all cases went on to serious disease. A few improved spontaneously and others progressed to reach a state of continual, severe spasm of the bronchioles.

The condition is relatively easy to differentiate from classical bronchial asthma, although it has been observed in persons known to have the classical disease as well. Tokyo-Yokohama "asthma" is considered by the patients as the less easily tolerated condition, particularly for the reasons that difficulty in breathing is almost continuous and response to therapy is minimal. In a period of a few months to a year, these patients develop permanent lung disability, probably in the form of pulmonary emphysema.

A similar condition was found in another American military group also stationed in an industrially developed area, the island of Okinawa. This was first discovered in 1956. It is interesting that some of the persons who had developed the condition in Okinawa and then improved when they left the island, had a relapse if they were stationed in the Tokyo-Yokohama area of Japan.

We in the United States have not experienced a condition similar to that of Japan. But we have

observed attacks of asthma, in epidemic proportions, related to air pollution. A few years ago in New Orleans, Louisiana, there were occurring outbreaks of asthmatic attacks among known patients with the disease. These attacks were associated with specific local wind conditions; analysis of the weather information showed that the attacks were most frequent when the winds were coming from a single direction and were of a low velocity. Further study indicated that when the light winds were blowing from some abandoned city dumps still smouldering underground, it was then that the outbreaks occurred. Recently it was found that when the winds blew in this manner and the asthmatics became ill, there was a larger amount than usual of a characteristic airborne particle in the air. This substance was shown to have been derived from burning fibrous plant material. When this material was extracted and used for skin testing, it was found that the patients who were known to develop the acute attacks were much more likely than the control patients to show specific sensitivity to these extracts.

The condition just described, in contradistinction to the asthmalike disease in Japan and Okinawa, is probably a true allergenic bronchial asthma. In the case of the Japanese disease we have what appears to be asthmatic bronchitis.

We have had other instances in the United States in which irritant air pollutants have been shown to precipitate attacks of bronchial asthma in asthmatics. This was found in studies in Pasadena, Calif., and Nashville, Tenn. At the present time we do not know the mechanism by which irritant airborne materials precipitate attacks of asthma. There are many possible hypotheses for this. From the point of view of the air pollution official, however, the significant fact is that asthma, or an asthmalike disease, can be induced by manmade community air pollutants.

Lung Cancer

Lung cancer has been constantly increasing during the last 50 years. This increase, especially marked among men, has occurred in most countries of the globe, but not at the same time or even in equal degree. There have been many factors cited as being apparently responsible for this disease reaching such near-epidemic proportions. Among the more important ones have been the following: improved diagnostic facilities; increased life span; smoking; genetic constitution; race; viral disease; occupational exposure; and air pollution.

Let us examine briefly some of the reasons why air pollution is believed to be one of the environmental factors contributing to the increase in lung cancer. This presentation must be viewed with the knowledge that the cause of human cancer generally is not now known, even though we do know that we can actually bring on cancer in certain animals treated in a special way.

Lung cancer occurs with higher frequency in cities than it does in rural areas with their lesser air pollution. This is found to be the case even when correction of the data is made for all the factors that can be recognized and controlled, including smoking, variation in population density, and occupation. The air of urban areas is known to carry more of the potential cancer producing agents than does the air in rural areas. In fact, one such investigation has shown a direct association between the varying amounts of benzo(a)pyrene (a laboratory-proved cancer producing agent) in the air and the variation in lung cancer death rate.

Four independent studies have shown that previous longtime residence in other countries with different degrees of air pollution was associated with varying incidences of lung cancer, the variation being dependent upon or associated with the factor of exposure in the earlier parts of life. Thus, in a group of immigrants to New Zealand and Australia from Great Britain, lung cancer mortality was higher than among native New Zealanders and Australians, even though they were all from a similar ethnic background and had similar smoking habits. In a group of immigrants to South Africa from Great Britain, the mortality from lung cancer was higher than among white South Africans who smoke even more than the British. In a Norwegian emigrant group to the United States it was found that the lung cancer occurrence was midway between that of the Norwegians who stayed at home and native Americans.

From the solid materials collected from filtered air there have been extracted various substances that were cancer producing when applied to the skin, or when injected into the subcutaneous tissues, of susceptible rodents. The important contribution made by the internal combustion engine, especially the automobile engine, in this connection has been amply demonstrated. Some of the substances emitted by the internal combustion engine are direct carcinogens (cancer producing agents); others may act as cocarcinogens. These observations do not mean, however, that these same materials will necessarily be cancer producing or cancer stimulating in the lung of man. This is only one link in the chain of required proof. Many intermediate steps will need to be taken between that of using a material that is chemically extracted from the air to directly induce skin cancer in susceptible mice and the occurrence of spontaneous lung cancer in a man breathing air contaminated with the same or similar material. In fact, it is only very recently that a lung cancer was induced in a monkey from the inhalation of a suspected potential carcinogen, in this case beryllium dust.

Other studies and experiments point to the possibility of certain air pollutants assisting the induction of cancer; that is, not serving as a direct cause, but acting as an important factor contributing to the cancer.

These bits and pieces of circumstantial evidence lead to the reasonable conclusion that air pollution is indeed one of the factors contributing to the increasing occurrence of lung cancer.

Summary

Air pollution, as it exists in some of our communities, contributes significantly as a cause or aggravating factor for the following medical conditions: acute respiratory infections, chronic bronchitis, chronic constrictive ventilatory disease, pulmonary emphysema, bronchial asthma, and lung cancer.

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